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CRYSTALLOGRAPHY.—*The ray-surface, the optical indicatrix, and their interrelation: An elementary presentation for petrographers.*[1] GEORGE TUNELL, Geophysical Laboratory, Carnegie Institution of Washington.

INTRODUCTION

The definitions of terms and the treatments of the elementary principles of optical crystallography in American text-books are in some respects unsatisfactory from the viewpoint of the petrographer. Clear and accurate statements are to be found in Pockels's "Lehrbuch der Kristalloptik," published in 1906. But Pockels's statements of elementary theory are scattered through mathematical discussions of more advanced problems, and for this reason apparently they have not received the attention that they deserve from American students of petrography. In order to make this material more readily available, the two fundamental theorems of optical crystallography are restated in this paper in very simple geometrical form without mathematical equations, and some of the chief applications of these theorems in petrography are discussed. A new geometrical construction is given for the first theorem in the case of biaxial crystals that is equivalent to the construction of Pockels but is simpler and much more easily visualized in practical applications.

ISOTROPIC SUBSTANCES

In substances belonging to the isometric system of crystallization or other isotropic substances, light of a single color emanating from a point-source radiates in all directions with equal velocities; at the end of unit time light of a single color will have traveled the same distance from the central point-source along each *ray*. The surface to which light has spread along all the rays is a sphere and this surface

[1] Received April 18, 1933.

is known as the *ray-surface*.[2] This surface is also sometimes called the *wave-surface*[3] because it represents the light wave that has spread out from the point-source as it exists for an instant at the end of unit time. In the present form of the wave theory the waves of light are electromagnetic waves, and the light is propagated in the form of transverse, electromagnetic vibrations. In isotropic crystals all directions perpendicular to a given ray-direction are possible *vibration directions* of rays having the given ray-direction.

UNIAXIAL SUBSTANCES

In crystals of the tetragonal and hexagonal systems, light of a single color traveling in any ray-direction oblique to the crystallographic c-axis has two different ray-velocities; moreover one of these ray-velocities varies with the direction. The ray-surface of such crystals consists of an ellipsoid of revolution and a sphere internally or externally tangent to it at the ends of the rotation-axis of the ellipsoid. The radii of the ray-surface represent the distances to which light travels along the rays in unit time. This two-sheeted surface is also sometimes called the wave-surface because it represents the double light-wave that has spread out from a point-source as it exists for an instant at the end of unit time. The vibration direction of any ray belonging to the spherical part of the ray-surface (such a ray is called an ordinary ray) is perpendicular to a section through the ray-surface containing the ray under consideration and the rotation-axis of the ray-surface (such a section is called a principal section of a uniaxial crystal). The vibration direction of any ray belonging to the ellipsoidal part of the ray-surface (such a ray is called an extraordinary ray) lies in the principal section and is assumed in the electromagnetic theory[4] to be parallel to the plane tangent to the ray-surface at the

[2] This statement and the remainder of this discussion apply to crystals without rotatory power. For petrographers, consideration of crystals with rotatory power is relatively unimportant, as Rosenbusch and Wülfing have stated. Those who desire information concerning the ray-surfaces of crystals with rotatory power, which are more complicated than the ray-surfaces of crystals without rotatory power, should consult Pockels's "Lehrbuch der Kristalloptik," pp. 307–309, also p. 332 (paragraph at top of page).

[3] This is the usage of Pockels, Wright, and nearly all other authors; Johannsen, however, applies the term wave-surface to a different surface (one to which it seems much less appropriate).

[4] At the present time it is no mere academic suggestion that petrographers adhere to the usage of the term vibration direction that is consistent with the electromagnetic theory. In the first place the only physical significance that can be attached to the basic concepts of optical crystallography today comes from the electromagnetic theory. In the second place, refractive indices and orientations of numerous anisotropic substances have recently been calculated approximately from a knowledge of their crystal structures by means of the electromagnetic theory. Such calculations are not intended to replace direct measurements of refractive indices, but are of great importance in correlating the different branches of crystallography—geometrical, optical, and structural.

end of the extraordinary ray under consideration. Thus in general the vibration direction of an extraordinary ray is not perpendicular to the ray.[5]

Geometrically associated with each ray is a *wave-front*. The wave-front of an ordinary ray is a plane perpendicular to the ray, since the ray-surface of the ordinary rays is a sphere. The wave-front of an extraordinary ray, however, is not perpendicular to it in general, but is a plane tangent to the ray-surface at the end of the extraordinary ray in question (that is, tangent to the ellipsoidal part of the ray-surface); this tangent plane is only normal to the extraordinary ray if the extraordinary ray be parallel or perpendicular to the rotation-axis of the ray-surface. The perpendicular distance from the central point-source of light to any plane wave-front (plane tangent to the ray-surface) is the measure of the velocity of the wave. Along the rotation-axis of the ray-surface all rays travel with the same velocity; moreover the wave-normals associated with these rays coincide with the rays in direction and the velocity of the waves is equal to the velocity of the rays. This direction of the ray-surface (the rotation-axis) is called the optic axis, and crystals of the tetragonal and hexagonal systems are called uniaxial because they have one (and only one) optic axis.

By definition the *refractive index* is equal to the reciprocal of the wave-velocity and, in general, it differs from the reciprocal of the ray-velocity.[6,7]

In applications of the theory of optical crystallography to practical problems of mineralogy and petrography, such as the determination of minerals, the directions perpendicular to the wave-fronts (these directions are called *wave-normals*) and the wave-velocities play more important rôles than the ray-directions and the ray-velocities. Thus Wright[8] says that:

[5] For a comparison of the newer usage with the older usage of the term vibration direction based on the solid elastic theory of light see TUNELL, G., and MOREY, G. W. Am. Mineral. 17: 365. 1932.

[6] This is the usage of Pockels, Wright, Rosenbusch, Wülfing, Niggli, Johannsen, Bouasse, and Duparc and Pearce. With this usage the fundamental law of refraction in anisotropic as well as isotropic crystals is expressed by the equation, $n = \frac{\sin i}{\sin r}$, where n denotes the refractive index, i the angle of incidence of the wave-normal in a vacuum, and r the angle of refraction of the wave-normal in the crystal. If the refractive index be set equal to the reciprocal of the ray-velocity then the refractive index does not enter the fundamental equation of refraction in the case of anisotropic crystals.

[7] The reciprocal of the ray-velocity has been called the ray-index in distinction from the refractive index. BORN, M. *Atomtheorie des festen Zustandes* (*Dynamik der Kristallgitter*) 2nd ed. p. 602. 1923.

[8] WRIGHT, F. E. *The index ellipsoid (optical indicatrix) in petrographic microscope*

"In rock thin-sections the crystal plates are very thin and most of the observations are made in either central or slightly oblique illumination. Under these conditions it is simpler and more direct to consider only the wave-front normals (i.e. directions perpendicular to the wave-fronts) and to leave the rays entirely out of the discussion. This statement does not mean that the significance of rays should be passed over in silence but simply that for the working petrographer the conception of the wave-front normals is sufficient to explain practically all the phenomena which he encounters."

In practical problems of mineralogy and petrography, as well as in problems of the theory of optical crystallography, it has been found extremely helpful to introduce another reference surface called the *optical indicatrix*. The optical indicatrix of a uniaxial crystal is an ellipsoid of rotation and, unlike the ray-surface, consists of a single sheet. The length of the radius along the rotation-axis of the indicatrix is set equal to the refractive index, ϵ, of an extraordinary wave propagated at right angles to the rotation-axis (all such extraordinary waves have the same refractive index); the length of the equatorial radius of the indicatrix is set equal to the refractive index, ω, of an ordinary wave. Each radius vector of the indicatrix represents a vibration direction and its length is the measure of the refractive index of a wave vibrating along it.

By means of the optical indicatrix one can solve the following two important practical problems very easily, as will be shown in the succeeding paragraphs.

Problem I. Given the direction of a ray, *OS*, with respect to the optical indicatrix (Fig. 1). Required to find the directions of the two wave-normals associated with it, also the refractive indices of the two waves, and lastly the vibration directions and velocities of the two rays propagated along *OS*. Construction: Pass a plane through the given ray, *OS*, and the optic axis, $O\epsilon$ (plane of the paper in Fig. 1). In the plane of the paper draw the diameter conjugate to the ray, *OS*. (Note. One diameter of an ellipse is conjugate to a second diameter if, and only if, the first diameter be parallel to the tangents to the ellipse at the ends of the second diameter.) Then OP_1, the conjugate to *OS*, is the vibration direction of the extraordinary ray propagated along *OS* and the normal to the plane of the paper is the vibration direction of the ordinary ray propagated along *OS*; moreover the distance, OP_1, represents the refractive index of the extraordinary wave, and the radius of the indicatrix normal to the plane of the paper represents the refractive index of the ordinary wave. Draw the line, ON_1,

work. Am. Journ. Sci. **35**: 135. 1913. With this discussion of Wright the present paper is in complete agreement. Niggli takes the same view. (*Lehrbuch der Mineralogie*, 1. *Allgemeine Mineralogie*. 2nd ed. p. 368. 1924.)

perpendicular to OP_1 in the plane of the paper. The line, ON_1, is the wave-normal of the extraordinary ray and the wave-normal of the ordinary ray coincides with OS. Lastly draw a perpendicular to the elliptical section at P_1; this perpendicular intersects OS in Q_1. Then $\frac{1}{P_1Q_1}$ is the velocity of the extraordinary ray propagated along OS,

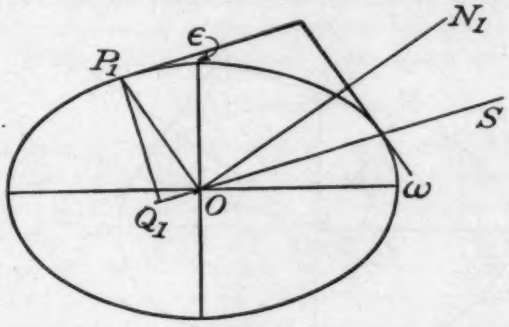


Fig. 1.—Section through the indicatrix of a uniaxial crystal illustrating the construction of Problem I.

and the reciprocal of the radius of the indicatrix normal to the plane of the paper is the velocity of the ordinary ray propagated along OS.

Problem II. Given the direction of a wave-normal, ON, with respect to the indicatrix (Fig. 2). Required to find the refractive indices of the two waves propagated along it, also the directions and velocities of the two rays associated with these two waves, and lastly the vibration directions of the two rays. Construction: Pass a plane through the wave-normal, ON, and the optic axis, $O\epsilon$ (plane of the paper in Fig. 2). In the plane of the paper draw OP_1 perpendicular to ON. Then OP_1 is the vibration direction of the extraordinary ray and the distance, OP_1, represents the refractive index of the extraordinary wave. The radius of the indicatrix perpendicular to the plane of the paper is the vibration direction of the ordinary ray and it also represents the refractive index of the ordinary wave. At P_1 draw the perpendicular to the elliptical section. Through O draw a line normal to the perpendicular from P_1; this normal, OS_1, intersects the perpendicular to the elliptical section in Q_1. Then OS_1 is the direction of the extraordinary ray and $\frac{1}{P_1Q_1}$ is the velocity of the extraordinary ray. The ordinary ray coincides with ON and its velocity is equal to the

reciprocal of the radius of the indicatrix perpendicular to the plane of the paper.

The construction of Problem II solves the standard problem of the determination of the extinction positions and birefringence of a thin-section of a mineral grain observed in approximately parallel light. In this case the incident wave-normal is assumed to be perpendicular to the plane, parallel-sided plate, and passes through the plate with-

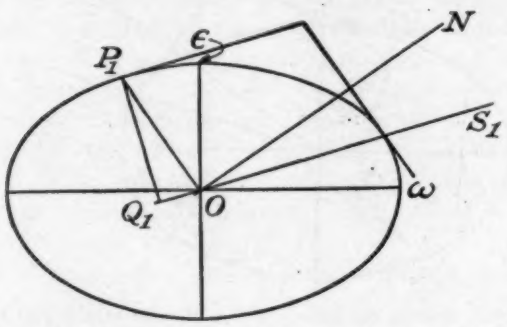


Fig. 2.—Section through the indicatrix of a uniaxial crystal illustrating the construction of Problem II.

out change of direction in accordance with the fundamental law of refraction. In the general case of a wave-normal in an isotropic medium striking an anisotropic crystal plate at any angle, the fundamental law of refraction is as follows:

$$n_0 \sin i = n_1 \sin r_1 = n_2 \sin r_2,$$

where n_0 denotes the refractive index of the isotropic medium, i the angle of incidence of the wave-normal, n_1 and n_2 the refractive indices of the plate for the two refracted wave-normals corresponding to the incident wave-normal, and r_1 and r_2 the angles of refraction of the two wave-normals inside the crystal plate corresponding to the given incident wave-normal. In the special case of a wave-normal incident perpendicularly the angles r_1 and r_2 are both zero; inside the crystal plate two waves are propagated along the given wave-normal with different wave-velocities, however. The vibration directions of the two rays associated with the two waves lie in the plane of the plate. A plane passed through the center of the indicatrix parallel to the plane of the plate intersects the indicatrix in an ellipse, the major and minor diameters of which are the vibration directions of the plate.

The difference in length of the major and minor radii of the ellipse is the measure of the birefringence of the mineral section.

Practical and theoretical problems concerning uniaxial crystals could be solved by means of the ray-surface almost as conveniently as with the indicatrix; the ray-surface of biaxial crystals is much more complicated, however, and the solution of most problems by means of it is impracticable. An oblique section of the ray-surface of a biaxial crystal is not composed of circles and ellipses but of more complicated curves not readily visualized without computation and plotting.

BIAXIAL SUBSTANCES

After the discovery of the form of the ray-surface of uniaxial crystals by Huygens the attempt was made by Young to generalize it and to obtain thus the ray-surface of crystals belonging to the orthorhombic, monoclinic, and triclinic systems (biaxial crystals), but the attempt was not successful. Sometime later, however, Fresnel succeeded in generalizing a single-sheeted reference surface analogous to the indicatrix, and from the generalized single-sheeted reference surface he obtained for the first time the true ray-surface of biaxial crystals.

The indicatrix of a biaxial crystal is a triaxial ellipsoid[9] the dimensions (diameters) of which, measured along the axes, are 2α, 2β, and 2γ, where α, β, and γ denote the principal refractive indices of the substance, $\alpha < \beta < \gamma$. Each radius vector of the indicatrix represents a vibration direction and its length is the measure of the refractive index of a wave vibrating along it. All plane sections passing through the center of the indicatrix of a biaxial crystal are ellipses except two, which are circles. The two circular sections include the intermediate axis of the triaxial ellipsoid (β-axis), and both circular sections have radii of length β. The directions perpendicular to the two circular sections are called the optic axes or binormals. There is a certain analogy between the optic axes of a biaxial crystal and the optic axis of a uniaxial crystal, since all wave-normals coincident with an optic axis of a biaxial crystal have the same refractive indices and have vibration directions in all azimuths in the circular sections; however, the analogy is not complete, since the rays corresponding to these wave-normals do not coincide with the wave-normals, with one exception in the case of the wave-normals along each optic axis.

[9] For the description and equation of a triaxial ellipsoid, see OSGOOD, W. F., and GRAUSTEIN, W. C. *Plane and solid analytic geometry*. pp. 548, 549. 1922.

For the equation of the indicatrix of biaxial crystals see ROSENBUSCH'S *Mikroskopische Physiographie der petrographisch wichtigen Mineralien*, 1: Erste Hälfte, 5th ed., WÜLFING, E. A. 1 Lief., p. 125. 1921, or POCKELS. *op. cit.*, p. 33.

In the indicatrix of a biaxial crystal, as in the indicatrix of a uniaxial crystal, a ray drawn in a random direction, the wave-normal associated with the ray, the vibration direction belonging to the ray and wave-normal, and also the perpendicular to the indicatrix at the

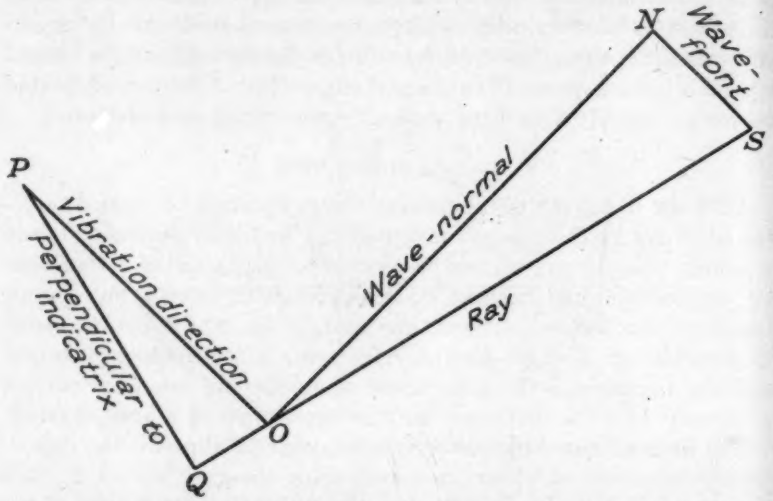


Fig. 3.—A ray drawn in a random direction, the wave-normal associated with the ray, the vibration direction common to the ray and the wave-normal, and the common perpendicular to the ray and the indicatrix at the end of the radius representing the vibration direction all lie in a plane. Legend: *OS*, ray; *ON*, wave-normal; *OP*, vibration direction; *PQ*, common perpendicular to ray and indicatrix at end of radius representing vibration direction.

end of the radius representing the vibration direction all lie in a plane; moreover the perpendicular to the indicatrix at the end of the radius representing the vibration direction is also perpendicular to the ray (Fig. 3).[10] Thus by means of the indicatrix one can solve two problems, I′ and II′, for biaxial crystals by constructions analogous to those already explained for uniaxial crystals. The problems and solutions are as follows.

Problem I′. Given the direction of a ray, *OS*, with respect to the optical indicatrix (Fig. 4). Required to find the directions of the two wave-normals associated with it, also the refractive indices of the two waves, and lastly the vibration directions and velocities of the two rays propagated along *OS*. Construction: Pass a plane through

[10] POCKELS, F. *op. cit.*, pp. 48, 52, 53. FLETCHER, L. *The optical indicatrix and the transmission of light in crystals.* pp. 32, 50, 51, 52. 1892.

the center of the indicatrix conjugate to the given ray, OS. (Note. A diametral plane is conjugate to a given diameter of a triaxial ellipsoid if, and only if, it be parallel to the planes tangent to the ellipsoid at the ends of the given diameter.)[11] The conjugate plane intersects the indicatrix in an ellipse (which in two special cases reduces to a circle); the major and minor diameters of this ellipse, P_1P_1' and P_2P_2', are the vibration directions of the two rays propagated along OS, and the distances, OP_1 and OP_2, represent the refractive indices of the two

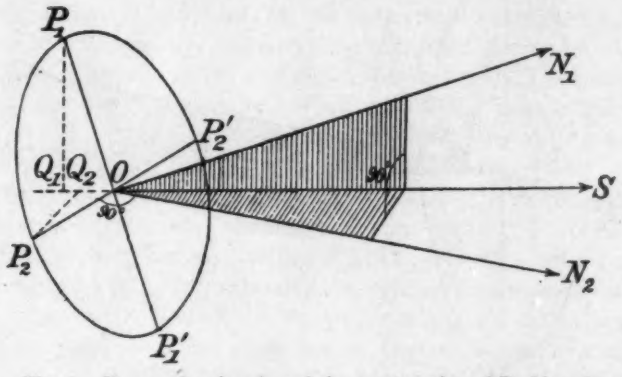


Fig. 4.—Perspective drawing of the construction of Problem I'.

waves associated with the two rays. The wave-normal corresponding to the ray propagated along OS and vibrating along P_1P_1' lies in a plane through OS and P_1P_1' and is normal to P_1P_1'. Similarly the wave-normal corresponding to the ray propagated along OS and vibrating along P_2P_2' lies in a plane through OS and P_2P_2' and is normal to P_2P_2'. Draw the perpendiculars to the indicatrix at P_1 and P_2; these perpendiculars intersect OS in Q_1 and Q_2. Then $\frac{1}{P_1Q_1}$ is the velocity of the ray propagated along OS and vibrating along P_1P_1', and $\frac{1}{P_2Q_2}$ is the velocity of the ray propagated along OS and vibrating along P_2P_2'. It may be noted in conclusion that the planes, SON_1 and SON_2, are perpendicular; in other words, the wave-normals, ON_1 and ON_2, lie in perpendicular planes the intersection of which is OS. P_1Q_1

[11] OSGOOD, W. F., and GRAUSTEIN, W. C. *op. cit.*, Unnumbered exercise immediately following Theorem 1 on page 570, also Theorems 3 and 4 on page 571. Or alternatively, SALMON, GEORGE A. *A treatise on the analytic geometry of three dimensions.* (Revised by ROGERS, R. A. P. 5th ed. 1: 90. 1912.

and P_2Q_2 also lie in the planes, SON_1 and SON_2, respectively, and P_1Q_1 and P_2Q_2 are both perpendicular to OS.[12]

Problem II′. Given the direction of a wave-normal, ON, with respect to the indicatrix (Fig. 5). Required to find the refractive indices of the two waves propagated along it, also the directions and velocities of the two rays associated with these two waves, and lastly the

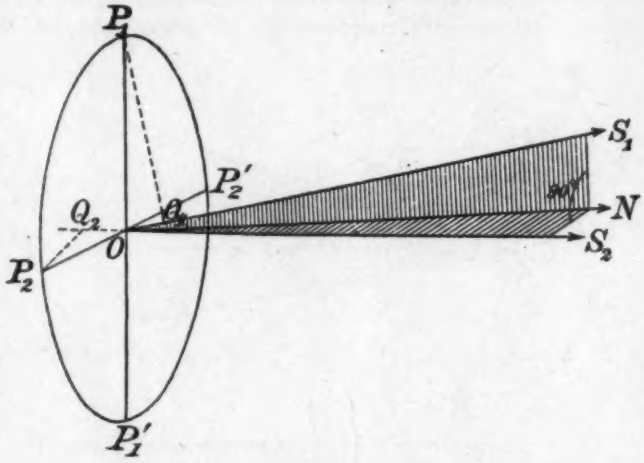


Fig. 5.—Perspective drawing of the construction of Problem II′.

vibration directions of the two rays. Construction: Pass a plane through the indicatrix perpendicular to the given wave-normal, ON. This plane intersects the indicatrix in an ellipse (which in two special cases reduces to a circle); the major and minor diameters, P_1P_1' and P_2P_2', of this ellipse are the vibration directions of the two rays corresponding to the given wave-normal, and the distances, OP_1 and OP_2, represent the refractive indices of the two waves propagated along ON. At P_1 and P_2 draw lines perpendicular to the indicatrix. Through

[12] The construction given in Problem I′ is based on that of POCKELS (*op. cit.* p. 54) and arrives at the same results, but reaches the results by a slightly different and considerably simpler route. Thus in the construction given here the elliptical section containing the vibration directions is obtained as a diametral section parallel to the tangent plane at the end of the given ray, whereas in Pockels's book the elliptical section is obtained as the plane section containing all the points of tangency of a cylinder the elements of which are parallel to the given ray. The construction used here has a very substantial advantage in practical problems since the tangent plane at the end of the given ray and the diametral plane parallel to this tangent plane are readily visualized as soon as the indicatrix and ray are given, whereas the tangent cylinder is difficult to visualize and even if pictured correctly offers relatively little aid to one's geometrical intuition in locating the desired elliptical section.

O draw lines normal to the perpendiculars from P_1 and P_2; these normals, OS_1 and OS_2, intersect the perpendiculars to the indicatrix in Q_1 and Q_2. Then OS_1 and OS_2 are the directions of the two rays corresponding to the two waves propagated along ON and vibrating along OP_1 and OP_2 respectively. The velocities of the rays, OS_1 and OS_2, are equal to $\frac{1}{P_1Q_1}$ and $\frac{1}{P_2Q_2}$ respectively. It may be noted in conclusion that the planes, NOS_1 and NOS_2, are perpendicular; in other words, the two rays, OS_1 and OS_2, lie in perpendicular planes the intersection of which is ON; moreover the vibration directions, OP_1 and OP_2, lie in the planes, NOS_1 and NOS_2, respectively. The lines, P_1Q_1 and P_2Q_2, also lie in the planes, NOS_1 and NOS_2, respectively, but, unlike OP_1 and OP_2, the lines, P_1Q_1 and P_2Q_2, are not themselves perpendicular in this case.[13]

The ray-surface[14] of a biaxial crystal can easily be developed from the indicatrix by means of the constructions given in Problem I′. A picture of a model of the ray-surface of a biaxial crystal (after Johannsen) is given in Fig. 6. In particular the principal sections of the ray-surface are readily deduced. In the plane of the indicatrix, $\beta\gamma$, two rays are propagated along each radius. One of these rays has the velocity, $1/\alpha$, in every direction in the plane, $\beta\gamma$, and gives rise to a circle. The other of these rays has a velocity that varies with the direction in the plane, $\beta\gamma$, from a minimum of $1/\gamma$ to a maximum of $1/\beta$, and gives rise to an ellipse. This ellipse lies wholly within the circle in the plane, $\beta\gamma$, since $1/\alpha > 1/\beta > 1/\gamma$. In the plane, $\alpha\beta$, two rays are propagated along each radius. One has the velocity, $1/\gamma$, in every direction in the plane, $\alpha\beta$, and gives rise to a circle. The other has a velocity that varies with the direction in the plane, $\alpha\beta$, from a minimum of $1/\beta$ to a maximum of $1/\alpha$, and gives rise to an ellipse. This ellipse lies wholly outside the circle in the plane, $\alpha\beta$, since $1/\alpha > 1/\beta > 1/\gamma$. In the plane, $\alpha\gamma$, also, two rays are propagated along each radius. One has the velocity, $1/\beta$, in every direction in the plane, $\alpha\gamma$, and gives rise to a circle. The other has a velocity that varies with the direction in the plane, $\alpha\gamma$, from a minimum of $1/\gamma$ to a maximum of $1/\alpha$ and gives rise to an ellipse. The ellipse and the circle in the plane, $\alpha\gamma$, intersect, since $1/\alpha > 1/\beta > 1/\gamma$, and their four common points are lettered u, u', u'', and u''' in Fig. 9. In the directions, uu' and $u''u'''$, there is only a single ray-velocity since the points, u, u',

[13] Based on the construction of Pockels. *op. cit.*, p. 54.

[14] For the equation of the ray-surface of biaxial crystals, see ROSENBUSCH and WÜLFING. *op. cit.*, p. 124, or POCKELS. *op. cit.*, p. 41.

u'', and u''' are common to both sheets of the ray-surface. The directions, uu' and $u''u'''$, are called the ray-axes or biradials. In most crystals the angle between an optic axis (binormal) and the adjacent

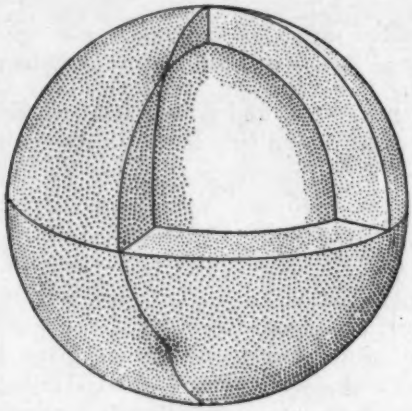


Fig. 6.—Model of the ray-surface of a biaxial crystal. (After Johannsen.)

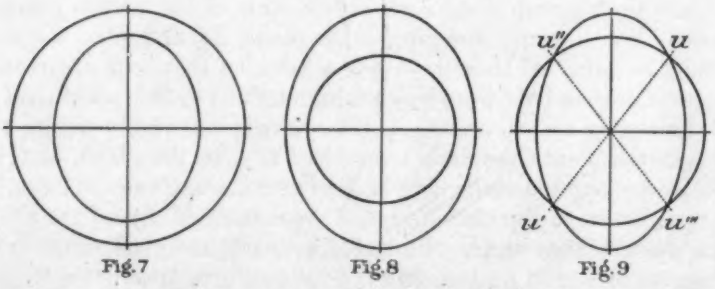


Fig. 7 Fig. 8 Fig. 9

Figs. 7, 8, 9.—Principal sections of the ray-surface of a biaxial crystal. In Fig. 7 the plane of the drawing is the plane, $\beta\gamma$, and the direction of the major diameter of the ellipse is that of the γ-axis; the direction of its minor diameter is that of the β-axis. In Fig. 8 the plane of the drawing is the plane, $\alpha\beta$, and the direction of the major diameter of the ellipse is that of the β-axis; the direction of its minor diameter is that of the α-axis. In Fig. 9 the plane of the drawing is the plane, $\alpha\gamma$, and the direction of the major diameter of the ellipse is that of the γ-axis; the direction of its minor diameter is that of the α-axis.

ray-axis (biradial) is very small, but the optic axes and the ray-axes do not coincide.

In theory it is true of biaxial crystals as well as of uniaxial crystals that all information obtainable from the indicatrix could be obtained

from the ray-surface (stated in another way, either of these two surfaces can be derived from the other); nevertheless in most problems the required quantities are more easily constructed from the indicatrix than from the ray-surface.

As Wright[15] has clearly pointed out, the indicatrix is more closely and directly connected with the experimental observations made in most petrographic work than any other reference surface. In such work, either with thin-sections or with powders immersed in liquids, the measurements of refractive index (by comparisons of refractive indices of two adjacent substances the index of one of which is known) are made with the aid of a polarizing prism.[16] Thus refractive indices are obtained bound together with the corresponding vibration directions. These measurements and observations are simply and unambiguously stated in terms of the properties of the indicatrix; on the other hand statements of these results in terms of the properties of the ray-surface are involved and confusing. One may mention the following typical example: Under the microscope one observes elongated crystals of an unknown mineral and finds by means of the central illumination or oblique illumination test, that its greatest refractive index, γ, is measured when the longest dimension of the crystals is parallel to the vibration direction of the polarizing prism;[17] then one knows that the γ-direction of the indicatrix is parallel to the longest dimension of the crystals. If it be next ascertained by measurement of interfacial angles (or coordinate angles of faces) with the reflection goniometer, by the measurement of interfacial angles with the Fedorov stage, or by measurement of interzonal angles with the microscope stage[18] that the longest dimension of the crystals is the crystallographic c-axis, one can write finally, $\gamma = c$. The determination of the orientation of the other two principal axes is accomplished and recorded in a similar manner. The determination of the orientation of crystals of the triclinic system requires a somewhat more complicated

[15] *Op. cit.*, pp. 133–138.

[16] For a discussion of the various immersion methods and references to explanations of their modes of application, see TUNELL, G., and MOREY, G. W. Am. Mineral. 17: 372–378. 1932.

[17] It is assumed here that only one polarizing prism is in the path of light through the microscope, the second polarizing prism being thrown out of the optical path.

[18] In the measurement of interzonal angles, that is, the angles between crystal edges, under the microscope, care must be taken to establish the parallelism of the plane containing the two edges with the microscope stage. This can be accomplished by the observation that both edges in question are sharply in focus throughout their entire lengths simultaneously; it can also be accomplished in special cases by observation of the interference figures of the crystals in convergent light. If the plane of the two edges be not parallel to the stage, the angle turned by the stage will not be the true interzonal angle and the measurement will be erroneous.

procedure and is most readily accomplished by means of the Fedorov stage.[19]

ACKNOWLEDGMENT

The author is indebted to Dr. H. E. Merwin and Dr. Tom. F. W. Barth for several valuable suggestions.

[19] For an excellent statement of the method of determining the orientation of the optical indicatrix of any substance with respect to the crystallographic axes by means of the Fedorov stage, see DUPARC, L., and REINHARD, M. *La détermination des plagioclases dans les coupes minces.* Mém. Soc. de Physique et d'Histoire Naturelle de Genève. 40: 72–101. 1924.

MINERALOGY.—*Properties of tri-calcium silicate from basic open hearth steel slags.*[1] OLAF ANDERSEN and HARLEY C. LEE.
(Communicated by ROBERT B. SOSMAN.)

A study of the constitution of slags was taken up by the writers at the Research Laboratory of the United States Steel Corporation several years ago.[2] In the course of our work, we succeeded in collecting samples containing relatively large individuals and sometimes well developed crystals of all the essential constituents of the slags. Since data on such constituents are meager and because any additional data will improve the accuracy of the microscopic work and will facilitate the future investigation of slags, we have taken advantage of the good material at our disposal and have devoted some time to coordinated determinations of the physical and chemical properties of most of the constituents of the slags. Chemical analyses have been made of the pure constituents separated from the slags and optical and other physical properties have been determined on material from corresponding samples. Whenever possible, crystallographic measurements have also been made. The complete results of our work are not yet ready for publication, but we find it of interest to report separately on our study of one of the constituents, tri-calcium silicate,[3] $3CaO \cdot SiO_2$.

Received June 10, 1933.

One of us (Lee) left the Research Laboratory of the United States Steel Corporation in 1931 and has since continued his work on slags intermittently at the Department of Mineralogy of the Ohio State University.

[3] After the completion of much of our work on the tri-calcium silicate about a year ago (May 1932) we were informed by Dr. John Johnston, Director of the Research Laboratory of the U. S. Steel Corporation, that Dr. A. Guttmann, Director of the Forschungsinstitut des Vereins deutscher Eisenportlandzementwerke in Düsseldorf, was interested in obtaining for his cement investigations a sample of slag containing tri-calcium silicate. Accordingly we sent Dr. Guttmann some of our material and jointly with Dr. Gille he has made a thorough study of it and is now anxious to publish his results without interfering with our interests. It is for this reason that we publish our results on the tri-calcium silicate without awaiting the conclusion of the work on

The slag.—The most suitable material for our investigations was obtained from the interior of large masses of slag (several tons) which had been tapped into ladles in the ordinary routine of steel making. Along the contacts with the ladle and at the exposed surface of such a slag, a solid crust will form quickly while inside the crust the cooling goes on very slowly and the slag may retain some of its volatile constituents till the last stage of the crystallization. These conditions are favorable for the growth of comparatively large and well developed crystals.

TABLE 1

ANALYSIS OF BASIC OPEN HEARTH SLAG CONTAINING TRI-CALCIUM SILICATE (JANITZKY)

SiO_2	11.70
TiO_2	0.38
P_2O_5	1.65
Al_2O_3	1.28
Fe_2O_3	4.54
FeO	14.87
MnO	8.70
MgO	9.36
CaO	46.59
S	0.20
Total	99.27

The constitution of the slags will not be described in detail in this paper. The following brief statements give the main features of composition and structure.

Analyses of basic open hearth slags of the type containing tri-calcium silicate as an essential constituent have been published by E. J. Janitzky,[4] whose samples are included among those studied by us. These analyses represent quickly cooled samples collected directly from the furnace. The slowly cooled slags from which we obtained our material for crystallographic and optic measurements were of the same type as those collected by Janitzky and have compositions close to that given in Table 1.

The main constituents of the slags dealt with are di-calcium silicate

the other slag constituents. The first part of Guttmann and Gille's paper, containing introductory discussions of cement problems, has been published in "Zement" for April 1933 under the title: *Zementtechnische Bedeutung und Feinbau des Trikalziumsilikats.* The remaining part will appear in the same journal Nr. 28 (July 13, 1933). We have been informed in advance of the results of their investigation and we have likewise communicated our results to them by sending them a copy of the manuscript of this paper.

[4] Yearbook American Iron and Steel Institute 1929, pp. 414–434. In Table 1 of Janitzky's paper the analyses marked Heat No. 1 2, 5, and 7 represent slags rich in tri-calcium silicate.

($2CaO \cdot SiO_2$) and tri-calcium silicate ($3CaO \cdot SiO_2$); important are also periclase (MgO), a magnetic oxide, and a lime-bearing ferrite; less important are crystallized lime (CaO), apatite (lime phosphate) and a constituent of uncertain composition, perhaps a modification of di-calcium silicate. Occasionally fluorite (CaF_2) is observed in slags to which much of this mineral has been added.

The constituents are not, as a rule, pure compounds, but usually solid solutions of two or more compounds one of which is predominating. Thus the lime silicates contain manganese and iron compounds and other admixtures, the periclase contains a considerable amount of iron oxides (magnesioferrite) in solid solution, and the magnetic oxide is a complex mixture of compounds.

The aggregates formed by these constituents vary considerably in composition and structure even within the same sample, and these variations clearly depend upon several factors besides rate of cooling. Some parts of a sample of slag may for instance contain abundant tri-calcium silicate together with di-calcium silicate, periclase, etc., while other parts of the same sample may consist largely of di-calcium silicate and periclase. In the latter case the residual liquid, from which tri-calcium silicate would usually crystallize, has been drained away from the loosely coherent aggregates of early crystals. Some parts of the slag may be compact and others vesicular, and the cavities sometimes contain constituents, such as apatite, that may not occur in the compact parts. The vesicular parts and the crystals occurring in the cavities have evidently been formed under the influence of volatile constituents retained in the slag, while the compact parts have crystallized from relatively dry melts. In many samples it is seen that the heavy crystals of oxide, formed at an early stage of the crystallization, have settled in the remaining melt and the bottom parts of such samples are therefore relatively rich in these oxide crystals. The rapidly cooled parts of a slag are relatively fine grained and often show a radial structure with thin plates of tri-calcium silicate arranged in sub-parallel or fan shaped groups (Figs. 1, 2, and 3). The slowly cooled parts are more coarse grained and have a more equant development of the crystal individuals (Figs. 4, 5, and 6). The tri-calcium silicate appears to have been among the last constituents to crystallize in the cavities as well as in the compact parts of the slag. It contains inclusions of the other constituents (Figs. 3, 4, 5, and 6).

Composition.—Material for the chemical analysis was obtained by mechanical separation of tri-calcium silicate from a coarse-grained

sample of slag. The crushed sample was classified into three fractions, −140+200 mesh (0.105-0.074 mm.), −200+325 mesh (0.074-0.044 mm.) and −325+400 mesh (0.044-0.039 mm.) and each fraction was treated individually in the following way: The magnetic constituents (oxide, periclase, and ferrite) were first removed by running the sample through a magnetic separator.[5] The non-magnetic residue consisted largely of a mixture of di-calcium silicate and tri-calcium silicate. By repeating the separation several times this mixture could be obtained almost free from magnetic impurities. The two silicates were

TABLE 2

ANALYSIS OF TRI-CALCIUM SILICATE EXTRACTED FROM A BASIC OPEN HEARTH SLAG
ANALYST: ELIZABETH KEEDICK LEE

SiO_2	22.77
TiO_2	0.18
P_2O_5	1.72
Al_2O_3	0.20
Fe_2O_3	0.76
FeO	2.01
MnO	1.20
MgO	1.29
CaO	68.65
Total	98.78
Gain on ignition	0.3

then separated by a heavy liquid consisting of methylene iodide slightly diluted with carbon tetrachloride (spec. gravity about 3.24). In this liquid the tri-calcium silicate would just float and the di-calcium silicate would sink together with other heavier impurities such as free lime and traces of the magnetic constituents. By repeated separations a material consisting of at least 98 per cent tri-calcium silicate and having di-calcium silicate as the only impurity of importance was obtained. We found that by proceeding as described we got better results than by making the separation directly in the heavy liquid without first extracting the magnetic constituents (all of which are heavy and therefore would sink together with di-calcium silicate). After the separation the three fractions of grain sizes of tri-calcium silicate were mixed. We had about 8 gr. of material for the analysis. The results are given in Table 2.

While the analysis shows about 86 per cent $3CaO \cdot SiO_2$ and thus about 14 per cent of impurities in the sample, microscopic examination indicates that about 12 per cent of this material is in solid solu-

[5] We used a modification of the laboratory separator described by HALLIMOND, A. F. Min. Mag. 22: 377–381. 1930.

tion in the tri-calcium silicate. Some idea of the large amount of material originally in solid solution can be had by referring to Fig. 14.

Crystallographic properties—Previous investigators have been in doubt with regard to the symmetry of the crystals. E. S. Shepherd,[6] and G. A. Rankin and F. E. Wright,[7] who first proved that tri-calcium silicate was a homogeneous compound, had only fine grained aggregates at their disposal and consequently could not obtain any definite data on the crystallographic properties. Certain observations on the optical properties made them think that the crystals possibly were monoclinic.

The numerous investigations of tri-calcium silicate as a constituent of Portland cement have made no appreciable addition to our knowledge of the crystallographic and optic properties of the compound,[8] because all these investigations have also been undertaken on fine-grained aggregates. It was not till the discovery of tri-calcium silicate in basic slags[9] that crystals of reasonable size were obtainable. Thus J. M. Ferguson[10] described crystals up to 5 mm. in diameter, without giving, however, crystallographic measurements or complete optical data. Ferguson thought that the crystals probably were orthorhombic.

For our crystallographic measurements we succeeded in picking out from the slags about 20 crystals ranging in size from 0.5×0.5×0.1 mm. to 3.0×3.0×0.5 mm. Some of these were only fragments, however, and none gave perfect signals for all faces on the same crystals. Nevertheless a sufficient number of coordinated measurements have been made to prove that the crystals belong to the trigonal system and have a rhomobohedral development. Most of the crystals examined, including all those measured for the determination of the axial ratio, came from the same sample from which the material for analysis was also extracted.

The most prominent form on all crystals (Figs. 7–10) is the basal pinacoid $C(0001)$. One or two rhombohedrons are also always present,

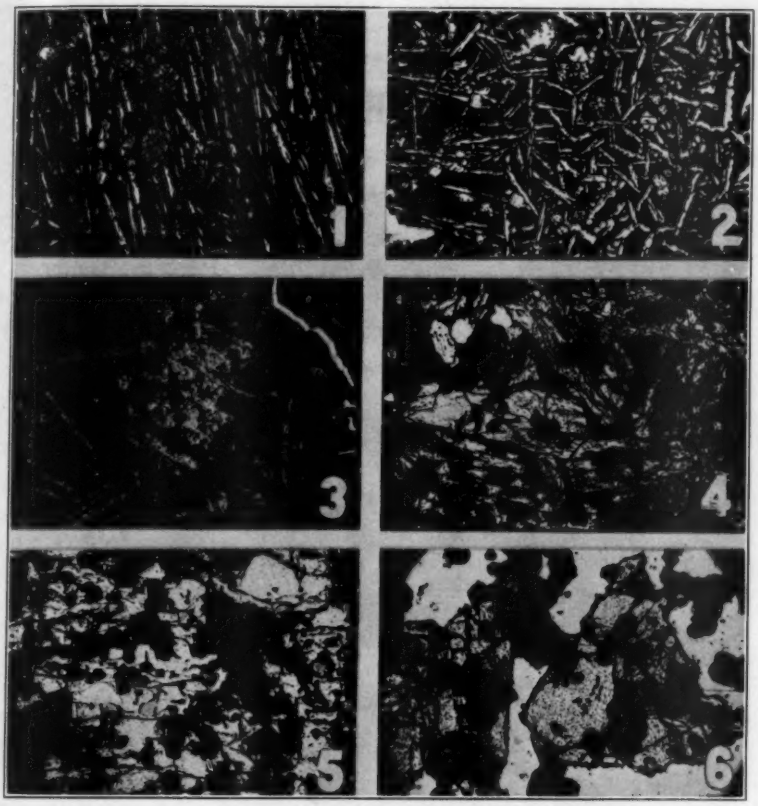
[6] SHEPHERD, E. S., RANKIN, G. A. and WRIGHT, F. E. Journ. Ind. and Eng. Chem. 3: No. 4. 1911. Also in Zeitschr. f. Anorg. Chem. 71: 20–44. 1911.

[7] RANKIN, G. A. and WRIGHT, F. E. Amer. Journ. Sc. (4) 39: 1–79. 1915.

[8] For a review of the literature up to 1926 see: BOGUE, R. H. *A digest of the literature on the constitution of Portland cement clinker*. Paper No. 3. Portland Cement Association Fellowship of the National Bureau of Standards, Washington, D. C. (Reprints from "Concrete" July 1926 to February 1927.) References to later publications are given by Guttmann and Gille (See footnote (3).)

[9] Dr. Wm. McCaughey, Professor of Mineralogy at the Ohio State University, has applied petrographic methods to the study of slags for many years and has probably been the first to observe tri-calcium silicate in slags.

[10] Royal Techn. College Met. Club Journal, 6: 9–12. 1927–28. Glasgow.



Figs. 1–6. Basic open hearth slags. Photomicrographs of thin sections. Ordinary light. Black areas represent ferrite and oxide, white or light gray areas largely tri-calcium silicate. Fig. 1—42×. Cross sections of thin plates of tri-calcium silicate. Round grains with cleavage lines: Periclase and lime. Fig. 2—30×. Plates of tri-calcium silicate in cross sections and a few in basal sections. Round or square spots, some with cleavage cracks: Periclase. Fig. 3—42×. Hexagonal basal section of tri-calcium silicate, with inclusions of oxide, surrounded by cross sections. Fig. 4—35×. Cross sections of thick crystal plates of tri-calcium silicate showing base and rhombohedrons. Fig. 5—35×. Large individual of tri-calcium silicate with inclusions of di-calcium silicate (slightly darker) and oxide (black). Fig. 6—35×. Triangular basal section (right) and cross section (left) of tri-calcium silicate with inclusions of di-calcium silicate (dark gray) and oxide (black). White areas: Voids in section.

but no other forms have been observed. One of the rhombohedrons is generally more conspicuous than the other and is present on all crystals. We have selected this as a positive rhombohedron, $R(10\bar{1}1)$. The

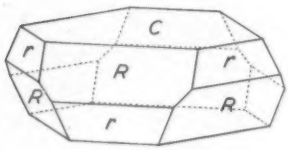


Fig. 7

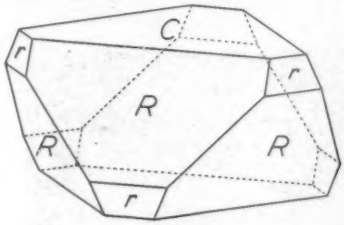


Fig. 8

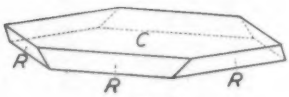


Fig. 9

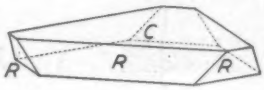


Fig. 10

Figs. 7–10. Crystal habits of tri-calcium silicate. Forms: $C(0001)$, $R(10\bar{1}1)$ and $r(\bar{2}021)$.

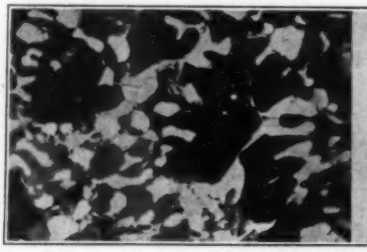


Figure 11.

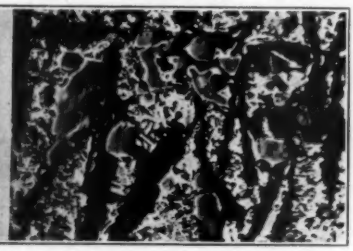


Figure 12.

Basic open hearth slags. Photomicrographs of polished surfaces. Fig. 11—67×. Dry objective. Surface etched with water. Black areas, some with hexagonal outlines: Tri-calcium silicate. Gray: Di-calcium silicate. White or very light gray: Periclase, oxide and ferrite. Fig. 12—100×. Oil immersion. Surface not etched. Black bands: Tri-calcium silicate. Other black areas: largely di-calcium silicate. Light gray areas with white rims: Periclase with oxide mantles. White: Oxide and ferrite.

other one, which is missing on some crystals and is very insignificant on others, then becomes the steeper negative rhombohedron $r(\bar{2}021)$. The characteristic zone relations of the various faces of these forms will appear from Figs. 7 and 8.

- The axial ratio $c:a = 1.7730$, calculated with the setting selected, agrees with that indicated by x-ray measurements. The crystallographic calculation is based on the average value for the angle $C(0001)$: $R(10\bar{1}1)$. The angles measured and those calculated from

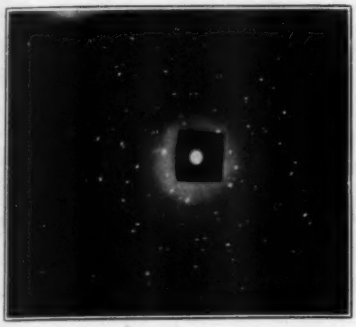


Fig. 13.—Laue photograph of tri-calcium silicate with x-ray nearly parallel to the *c*-axis. Reduced to one half of original photograph.

Fig. 14.—About 300×. Photomicrograph of clear tri-calcium silicate grain after reheating to 900°C showing lamellae of calcium ferrite formed by unmixing of solid solution.

TABLE 3

CRYSTAL ANGLES OF TRI-CALCIUM SILICATE

Angles	Measured			Calculated
	Number of angles measured	Limits	Mean	
$C(0001):R(10\bar{1}1)$.....	23	63° 48′ 64° 8′	63° 58′	
$C(0001):r(\bar{2}021)$.....	8	76° 8′ 76° 19′	76° 15′	76° 17′
$R(10\bar{1}1):R(1\bar{1}0\bar{1})$.....	3	77° 45′ 77° 46′	77° 45′	77° 49′
Angles $C:R$ in three different zones of one crystal....			64° 4′ 64° 0′ 64° 1′	
Azimuth angles between three zones $C:R$ on one crystal, measured on two-circle goniometer..			119° 58′ 120° 1′ 120° 1′	120° 0′

the axial ratio are given in Table 3. Of these measurements those stated in the lower part of the table give ample proof of the trigonal symmetry of the crystals.

The most common habits of the crystals are those shown in Figs. 7 and 8, representing thick basal plates with distinct development of the faces of both rhombohedrons. Less common in the slowly cooled slags, but evidently universally present in rapidly chilled samples, are the very thin basal plates of the types shown in Figs. 9 and 10. Both these have only one rhombohedron, *R*, but they differ in the development of the faces. In the crystal represented in Fig. 9 there has been an equal development of all faces of the rhombohedron and the plates consequently have hexagonal outlines. In the crystal of Fig. 10, on the other hand, the growth has been more rapid in one direction of the *c*-axis than in the other, and a triangular development of the plates has resulted. No indication of twinning is seen on any of the crystals examined.

With regard to the class of symmetry to which the tri-calcium silicate may belong, the crystallographic data give no final information. Neither could we obtain etching figures sufficiently distinct for a decisive conclusion. All that can be stated is that nothing in our crystallographic observations contradicts the assumption that the crystals have the symmetry of the di-trigonal scalenohedral class, the class to which most trigonal crystals belong.

We have studied the structure of these tri-calcium silicate crystals by means of x-ray diffraction patterns, using both the Laue and the fine powder method. While we have not completely worked out the crystal structure, our preliminary work indicates that the unit cell is rhombohedral. The x-ray data also indicate that the crystallographic axial ratio of $c:a = 1.773$, is probably the correct ratio for the unit cell.

We have included a Laue photograph of one of the clear dark green crystals (Fig. 13) showing the rhombohedral symmetry. The photograph was taken with a molybdenum target with a tube potential of 30,000 volts. The plate to crystal distance in this case was 5 centimeters.

Physical properties—The crystals have a poor cleavage parallel to the base, barely visible in thin sections (Figs. 4 and 5). They are very brittle and often full of cracks and have an uneven fracture. The hardness is slightly higher than 5, but lower than 6.

The specific gravity was determined with a pycnometer on the

material prepared for analysis and on another preparation from the same sample of the slag. Since water attacks tri-calcium silicate the powder was imbedded in α-monobromnaphthalene. The values found were $d\left(\frac{30°}{4°}\right) = 3.233$ and 3.215. The mean, $d\left(\frac{30°}{4°}\right) = 3.224$, may be regarded as representing the crystals described in detail in this paper. Other samples gave slightly different values.

The natural color of the crystals collected from slowly cooled slags is light olive green or brown. The fine powder is light gray with a brownish tinge caused by the numerous inclusions; the streak is light gray, almost white. The faces of fresh crystals have a glassy lustre, but when exposed to moist air for some time they become dull or sometimes iridescent.

Crystals occurring in lime lumps collected directly from the furnace and therefore quickly cooled, were dark olive green and almost perfectly clear and free from inclusions. When such clear crystals were heated for one hour in an electric furnace in air at 900°C they developed oriented lamellae (Fig. 14). These inclusions are reddish brown in color, are anisotropic, have a high index of refraction, and resemble dicalcium ferrite in appearance.

When these crystals are heated for about one hour at 1000°C some small di-calcium silicate crystals are found in the tri-calcium silicate grains. Crystals heated in air on platinum at 1400°C consist mostly of beta di-calcium silicate with some free lime. Part of the beta di-calcium silicate sometimes inverts to the gamma form on cooling.

The greenish color is probably due to ferrous iron compounds in solid solution in the tri-calcium silicate. On heating in air, this iron oxide is apparently oxidized to the ferric state and precipitated as a calcium ferrite.

The formation of a calcium ferrite compound due to oxidation with the resulting change in equilibrium, may explain the formation of di-calcium silicate at low temperatures in these crystals.

Optical properties. Appearance in thin sections.—Thin sections or small grains of the tri-calcium silicate are colorless in transmitted light. Thick sections, crystal plates or large grains are light yellow or brownish with an olive tinge. No pleochroism is observed. When mounted in Canada balsam the sections have a high relief and a pitted surface (Figs. 4, 5, 6). They have many irregular fractures and sometimes show fairly regular cleavage cracks parallel to the elongation of cross sections of the tabular crystals (vibration direction ω).

In thin sections of the slag most of the grains of tri-calcium silicate appear to be perfectly homogeneous except for the easily recognized inclusions of the other constituents of the slag. No twinning is observed, and all the homogeneous grains that have orientations suitable for conoscopic observation show decidedly uniaxial interference figures in accordance with the crystallographic properties described above. Some of the grains, however, contain irregular areas showing negative biaxial interference figures with small, variable axial angles and grading insensibly over into the surrounding uniaxial areas. The same phenomenon is more distinctly observed in thick crystal plates imbedded in an immersion liquid. In such plates some of the biaxial areas are seen to have sharp boundaries against the uniaxial areas and appear to represent inclusions of thin, irregular lamellae of foreign crystals in the tri-calcium silicate. The properties of these inclusions cannot be accurately determined, but they have a refractive index only a little different from that of tri-calcium silicate and a birefringence much higher. The inclusions are colorless and may show a faint indication of irregular twinning. These properties agree with those of di-calcium silicate in one of its high-temperature modifications and we believe that the assumption of such lamellar inclusions give a reasonable explanation of the optical anomalies of the tri-calcium silicate.[11] Considering the nature of the material in which the tri-calcium silicate occurs and its mode of formation the presence of lamellae of di-calcium silicate intimately intergrown with it should not be surprising. Since the amount of lamellae necessary to produce optical anomalies of the nature described is very insignificant (a small fraction of one per cent would certainly be sufficient) these inclusions can hardly influence the results of the analysis to any appreciable extent.[12] Neither can they have any measurable effect on the general physical properties of the crystals. Accordingly we find that the biaxial interference figures shown by parts of the crystals give no reason to postulate a deviation of the symmetry of the crystals from that of the trigonal system and to assume a monoclinic or orthorhombic symmetry with pseudo-uniaxial development such as has been done by previous investigators. The biaxial interference figures may be explained as an optical anomaly in the way indicated and it should be

[11] Any thin double refractive lamella (except one of a uniaxial crystal perpendicular to the optic axis) when superimposed on a basal section of a uniaxial crystal, will distort the interference figure and may easily produce the semblance of a biaxial figure.

[12] An admixture of one per cent $2CaO \cdot SiO_2$ would produce a deviation of about 0.1 per cent CaO and SiO_2 from the figures for pure $3CaO \cdot SiO_2$ and its influence would thus be within the limits of error of an ordinary analysis.

emphasized that such anomalies have been frequently observed in many other crystals the true uniaxial symmetry of which is generally accepted (for instance apatite, beryl, and zircon).

The crystals of tri-calcium silicate were too small and brittle to permit the grinding of prisms for the most accurate determination of the

TABLE 4

REFRACTIVE INDICES OF TRI-CALCIUM SILICATE (MEASURED ON ANALYZED SAMPLE)

$\lambda(10^{-7}$ cm)	ω	ϵ
535.1 (Tl)	1.733	1.728
589.3 (Na)	1.724	1.719
670.8 (Li)	1.714	1.709

refractive indices, but good determinations of the birefringence ($\omega - \epsilon$) and of the index for the ordinary ray (ω) could be made nevertheless.

The birefringence was determined on plates perpendicular to the base, measuring the path difference with the Berek compensator and the thickness with a micro-caliper. It was found to be 0.005 ± 0.0005

TABLE 5

REFRACTIVE INDICES OF VARIOUS SAMPLES OF TRICALCIUM SILICATE

ω_{Na}	ϵ_{Na}
1.722	1.717
1.726	1.720
1.732	1.726

for all wave lengths between red and violet. The index ω was determined in immersion liquids on plates and grains by Merwin's dispersion method.[13] Various determinations, made on crystals and grains from the same sample that furnished material for the crystallographic measurements and the analysis, gave results in agreement with one another within the limits of error of the method (± 0.001). These results are stated in Table 4. It is seen that there is a considerable dispersion of the refractive indices. The indices for sodium light are somewhat higher than those found by Wright[6,7] on pure tri-calcium silicate (average index for white light approximately 1.715, birefringence not higher than 0.005). This is naturally explained by the fact that the crystals examined contain small amounts of manganese and ferrous compounds, and other admixtures, in solid solution.

Besides the determinations stated above, we have made numerous scattered determinations of refractive indices on material from vari-

[13] MERWIN, H. E. and LARSEN, E. S. Amer. Journ. Sci. (4) 34: 42–47. 1912. POSNJAK, E. and MERWIN, H. E. Journ. Amer. Chem. Soc. 44: 1970. 1922.

ous other samples the crystals of which were not analyzed and could not be measured crystallographically. Examples of some of these determinations are given in Table 5. The quite considerable variation in these indices must clearly be due to variations in the composition of the crystals, probably largely in the amounts of ferrous and manganese compounds taken up by the tri-calcium silicate. Possibly the presence of comparatively large amounts of lamellar intergrowths of di-calcium silicate may have something to do with these variations.

Appearance in polished surfaces.—The examination of polished surfaces of slags under the microscope in reflected light may give valuable information supplementing the data obtainable with the petrographic microscope. This is especially true with regard to the opaque or semi-opaque constituents of the slag, but also the transparent constituents may be profitably studied in reflected light when all the possibilities of the method are taken advantage of. We have used this method extensively in our work on the constituents of steel slags and record here briefly our observations on tri-calcium silicate. The identification of the constituents on polished surfaces has always been verified in thin sections or powdered preparations of the same sample.

On polished surfaces that have not been exposed to moisture for any length of time, or on surfaces polished on a dry cloth, there is no very clear distinction between tri-calcium silicate and the other silicates of the slags. They all show the same gray color when observed with a dry objective and all appear practically black with occasional dots of interior reflections when an oil immersion objective is used. Sometimes crystal outlines against constituents having a different reflecting power may be seen. This is the case in the surfaces represented in Figs. 11 and 12.

In Fig. 12 the tabular crystals of tri-calcium silicate are seen in cross sections with an immersion objective. Besides the long black bands representing tri-calcium silicate there are other black areas, some irregular and some with rounded outlines. Most of these represent di-calcium silicate and except for the outlines of the grains there is no sure way of distinguishing the two constituents. In order to bring out the difference clearly etching must be used.

Fig. 11 represents an etched surface showing basal sections with hexagonal outlines of a number of crystals of tri-calcium silicate. The observation is made with a dry objective and the contrast between tri-calcium silicate and di-calcium silicate is brought out by the etching. The reagent in this case was distilled water applied to the surface

for about ten minutes at room temperature. This treatment produces on the surfaces of tri-calcium silicate a film showing vivid interference colors and makes the polishing scratches reappear. At the same time the grains of di-calcium silicate show almost no effect of the etching and appear with the original smooth surface and gray color of reflection. A prolonged etching with water, however, will affect also the di-calcium silicate and will bring out its twinning structure. The same may be accomplished more quickly by using other reagents such as 5 or 10% solutions of NH_4Cl in water, or of weak acids like perchloric acid and chromic acid. Merely dipping the polished surface into one of these solutions will produce striated films on the grains of di-calcium silicate while the tri-calcium silicate will become dull with a dark pitted surface in reflected light.

The relief in polished surfaces is very nearly the same for tri-calcium silicate, di-calcium silicate, and the lime-bearing ferrite. All these constituents appear with a low surface against which the grains of periclase, lime, and magnetic oxide stand out in high relief. The ferrite has a relatively high power of reflection (almost white with dry objective) and so has the oxide. The power of reflection of lime is medium (light gray) and that of periclase variable depending upon its contents of iron oxides (from gray to almost white).

Thus each one of the constituents has its characteristic properties (only a few of which are indicated above) by which it can be distinguished from the others on polished surfaces. It is of particular interest to emphasize here that the tri-calcium silicate can be recognized on polished surfaces and especially that it can be distinguished from its most important associate, the di-calcium silicate.

ACKNOWLEDGMENTS

We are greatly indebted to Mrs. Elizabeth Keedick Lee for having made a careful analysis of the tri-calcium silicate for us. To Dr. Wm. McCaughey, Chairman of the Department of Mineralogy of the Ohio State University, our thanks are due for the kind interest he has taken in our work by placing the facilities of the Department at the disposal of one of us (Lee) and by giving us some of his samples of slag and supporting us with advice and help. We are also indebted to Messrs. C. L. Kinney, E. J. Janitzky and M. J. Devaney of the Illinois Steel Company and Mr. H. B. Siddall of the American Bridge Company for helpful cooperation in obtaining most of the samples used in this investigation. Mr. Nicholas Bryker has given us valuable assistance throughout our work.

PALEONTOLOGY.—*Report on species of corals and larger foraminifera collected in Cuba by O. E. Meinzer.*[1] THOMAS WAYLAND VAUGHAN, Scripps Institution of Oceanography, LaJolla, Calif.

PREFATORY NOTE

This paper furnishes a setting for the list of fossils published under the title, "Report on species of fossils collected in Cuba by E. O. Meinzer in November and December, 1915" by T. Wayland Vaughan,[2] as an appendix to Doctor Meinzer's article "Geologic reconnaissance of a region adjacent to Guantanamo Bay, Cuba."[3]

It is essential for its proper interpretation and was intended to precede that list. It contains an account of the nomenclature of the species involved, the characterization of a new variety, and the discussion of problems of broad regional geologic correlation.

INTRODUCTION

Descriptions of species of corals and foraminifera collected by Dr. Meinzer have appeared in several papers. The Tertiary corals were described by me (Vaughan, 1919), and those descriptions, identifications, and stratigraphic references stand except that the foraminifera from locality 7522 are Eocene, while the corals seem to be Oligocene. My identification of *Diploastrea crassolamellata* from it has been confirmed by Mr. J. W. Wells. Specimens from two horizons appear to have been mixed by the transportation of specimens from a higher to a lower horizon.

Doctor Cushman published the first account of the larger foraminifera (Cushman, 1919) and later I discussed them in two papers (Vaughan, 1924 and 1926). I have endeavored to make a careful restudy of the Cuban material. The task was a difficult one. Since the examinations were based largely on thin sections of organisms that exhibit bewildering variation. I have been led to change some of Doctor Cushman's identifications. Table 1 is taken from Cushman's work already cited.

NOMENCLATURE OF SPECIES

Except to place the species referred to "*Orthophragmina*" in the older genus *Discocyclina*, those species are not changed. The species referred to *Carpenteria* are also left as they were. *Lepidocyclina perun-*

[1] Received May 19, 1933.
[2] This JOURNAL, 23: 261–263. 1933.
[3] Idem, pp. 246–260.

TABLE 1. DISTRIBUTION OF OTHER CUBAN FORAMINIFERA ACCORDING TO STATIONS AT WHICH FOUND

		3 3 4 4 3 5	3 3 4 4 7 8	3 3 5 5 6 7	3 5 5 1 1 2	3 5 5 1 1 6	3 5 5 1 1 8	3 5 5 1 2 1	3 5 5 2 2 2	3 5 5 2 3 3	3 5 5 4 3 8	3 5 5 4 5 4	3 5 5 6 6 6	3 5 5 6 6 7	3 6 1 1 7 8	3 6 1 1 9 0	3 6 1 1 2 2	3 6 1 1 2 3	3 6 1 1 2 4	3 6 1 1 2 5
Orthophragmina	*cubensis* Cushman	X		X										X	X	X	X	X	X	X
	subtaramelli Cushman		X																	
	sculpturata Cushman			X																
	crassa Cushman		X																	
	pustulata Cushman			X																
Lepidocyclina	*crassata* Cushman	X																		
	perundosa Cushman				X			X												
	subvaulinii Cushman				X															
	morgani Lem. & R. Douv.					X		?	?	X	X	X								
	schlumbergeri Lem. & R. Douv.						X		X	?	X	X								
	marginata (Micht.)					?	X	X				X								
	sumatrensis (Brady)					X					X									
	canellei var. *yurnagunensis* Cushman													X						
Carpenteria	*proteus* Cushman																			
	americana Cushman																			

dosa and *L. subraulinii*, both Eocene species, also remain as they were, but the other identifications of *Lepidocyclina* are changed.

Lepidocyclina canellei var. *yurnagunensis* is considered a valid species and I have redescribed it as *Lepidocyclina yurnagunensis* Cushman (Vaughan, 1926). The specimens identified by Cushman as *Lepidocyclina sumatrensis* and *L. morgani* are now referred to *L. yurnagunensis*. The specimens identified as *L. morgani* have both embryonic and equatorial chambers similar to those of *L. yurnagunensis*, but differ by possessing strongly developed pillars. There is complete intergradation between the forms without and with the pillars. In order to indicate the deviation from the typical form of the species, I propose to call this variant *Lepidocyclina yurnagunensis* var. *morganopsis*, n. var. (co-types from loc. 7543). Externally the specimens resemble *L. morgani* and also *L. parvula* Cushman, but as stated above the embryonic and equatorial chambers are like those of *L. yurnagunensis*.

Lepidocyclina crassata Cushman, at least part of the specimens identified by Cushman as *L. marginata* Micht., and *L. chattahoocheensis* Cushman (Cushman, 1920), are all placed in the synonymy of *L.* (*Eulepidina*) *favosa* Cushman (Cushman, 1919, Vaughan, 1924). The names *L. crassata* and *L. favosa* were published by Cushman at the same time, but I am selecting *L. favosa* as the name of the species because specimens free from the matrix can be obtained at the type locality of *L. favosa*, and the type of *L. crassata* is embedded in rock. The amount of variation in this species is most astonishing. Fortunately I have had available hundreds of perfectly preserved specimens from a single bed at one locality, Espinal, Vera Cruz, Mexico, in addition to good representations of all forms from their respective type localities. The specimen from locality 7522 identified by Doctor Cushman as *L. crassata* does not belong to the species.

The specimens identified by Cushman from Doctor Meinzer's localities nos. 7512, 7518, and 7543 as *L. schlumbergeri* are now referred to other species. Some of the specimens represent *L. gigas* Cushman. The specimens collected by Doctor Darton at locality 7664 belong to a large species of the subgenus *Eulepidina* distinct from *L. gigas*.

Doctor Meinzer's collections of orbitoidal foraminifera from localities 7512, 7513, 7516, 7518, 7519, 7543, 7548, 7552, 7553, and 7554, are all of approximately the same horizon in the Oligocene. This horizon is represented in Antigua, Jamaica, Cayman Brac, the State of Vera Cruz in Mexico, and at other localities in the Caribbean and

Gulf of Mexico regions. The horizon of locality 7521 is doubtful. It may be Eocene.

Locality 7522. The foraminifera are definitely Eocene. It contains two or more species in common with the Eocene exposure at Nuevitas, Cuba, U.S.G.S. loc. 3478, and species represented at other Eocene localities in Cuba. The corals collected at this locality seem to have come from another, an Oligocene, horizon.

If I noticed specimens of *Globigerina* and nullipores I recorded their presence. The presence of nullipores, if they are *in situ*, indicates relatively shallow water, because they are photosynthetic organisms; while the presence of *Globigerina* indicates that pelagic organisms drifted into the locality where the other fossils were found.

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VAUGHAN, THOMAS WAYLAND. 1919. *Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent coral reefs.* U. S. Nat. Mus. Bull. **103**: 189–524, *pls.* 68–152, 22 *text-figs.* 1919. (See p. 204.)

1924. *American and European Tertiary larger Foraminifera.* Geol. Soc. Amer. Bull. **35**: 785–822, *pls.* 30–36. 1924.

1926. *Species of* Lepidocyclina *and* Carpenteria *from the Cayman Islands.* Quart. Jour. Geol. Soc. **82**: 388–400, *pls.* 24–26. 1926.

BOTANY.—*Several more fungi that prey on nematodes.*[1] CHARLES DRECHSLER, Bureau of Plant Industry.

A fungus with long, narrow, straight or somewhat curved conidia, provided with 5 to 15 septa (Fig. 16 A) and borne on erect, aerial, only slightly differentiated hyphae, usually singly (Fig. 16, A, *a*) but sometimes, following continued growth of the hypha, in small number (Fig. 16 A, *b*), was found actively destroying slender nematodes referable to a species of *Rhabditis*. The animals were snared in rather small, intramatrical, non-constricting hyphal loops (Fig. 16, B) attached singly at a noticeable swelling in one of the three component cells by a relatively delicate, often somewhat curving stalk. Often the organ of capture was torn from its attachment by the struggling nema (Fig. 16, C, *a*), which then was frequently further snared in one or two other hyphal loops before finally succumbing to extensive internal hyphal invasion (Fig. 16, C, *b*). This invasion regularly proceeded

[1] Received June 9, 1933.

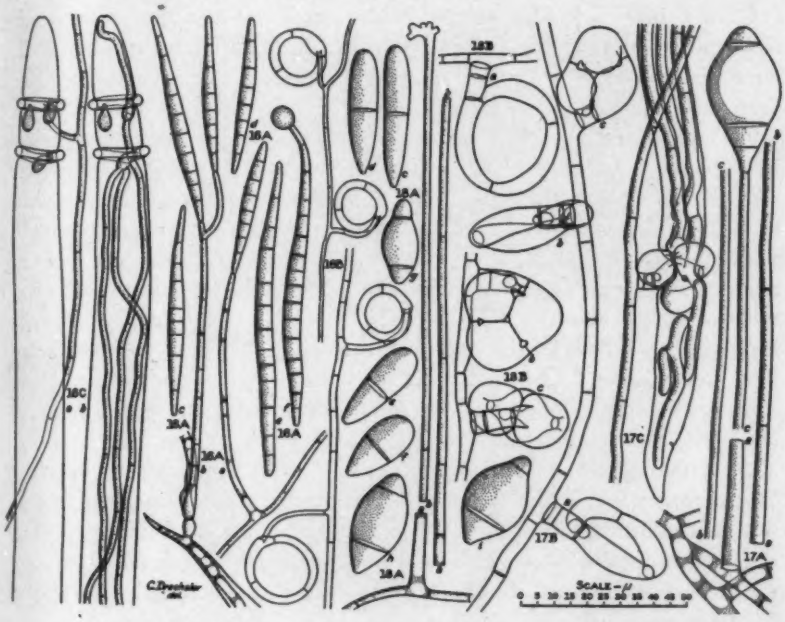
from one or more bursiform outgrowths thrust into the animal immediately following narrow perforation of its integument, the outgrowths being evidently too small to produce serious effects directly.

A fungus bearing terminally on tall, erect conidiophores (Fig. 17, A), solitary, 3-septate conidia strongly resembling in size, shape and septation those of the fungus previously shown in Figure 5,[2] as well as the 3-septate spores frequent in the fungus represented in Figure 12, was found very destructive to nemas referable to the genera *Rhabditis* and *Cephalobus*. The organs of capture here, however, correspond to those produced by the fungi shown in Figures 10, 13 and 14, similarly consisting of mostly vertically oriented, sturdy loops each composed regularly of 3 cells and attached by a short, stout, usually 2-celled stalk, the third loop-cell being fused terminally both to the basal portion of the first loop-cell and to the distal stalk-cell (Fig. 17, B, *a*, *b*); and similarly through pronounced swelling of the loop-cells (Fig. 17, B, *c*) constricting the animal nearly to death before initiating mycelial invasion (Fig. 17,C). The constricting loops here, as also those of the other forms producing them, and as, indeed, even the extensive systems of anastomosing adhesive superficial loops like those produced by the fungus shown in Figure 5, are sometimes torn from their attachments by the struggles of especially vigorous nemas, the uprooted apparatus, nevertheless, just as in the case of the non-constricting solitary loops characteristic of the fungi shown in Figure 6 and 16, usually continuing in its destructive function.

Since organs of capture are generally absent when any of the predacious Hyphomycetes isolated so far (those shown in Figs. 1–7, 9, 12–15, 16–18) are grown in pure culture on agar media of various compositions, it would seem that a tactile stimulus supplied in nature by living nemas, may be of moment for their production. Constricting loops (Fig. 18, B, *a*) in great abundance were produced by a fungus in an agar plate culture free of nematodes but liberally infested with mites. Many of the loops were "sprung" (Fig. 18, B, *b*, *c*), though apparently no mites were captured in them. The fungus in the mite-infested culture gave rise to conidia showing all gradations from an elongated 1-septate type to a strongly inflated 2-septate type (Fig.

[2] As the present summary constitutes a continuation of two earlier summaries concerning nema-capturing fungi, the numbering of the figures is made continuous throughout, so that all citations of figures given herein and bearing numerals from 1 to 11 refer to the first paper (this JOURNAL **23**: 138–141. 1933) and those bearing numerals from 12 to 15 inclusive refer to the second (this JOURNAL **23**: 267–270. 1933).

18, A, *c–i*), thereby abating somewhat the distinctness of the two types of conidia produced by fungi snaring nemas in constricting loops. As in pure culture virtually only spores of the elongated 1-



Three nema-capturing fungi, each numeral denoting a species separate from the others, and all drawn with the aid of the camera lucida at the same magnification; ×500.

Fig. 16.—A, Conidiophores and conidia: *a*, conidiophore of usual type bearing a single conidium; *b*, conidiophore arising from a killed nema and bearing 2 conidia; *c*, *d*, conidia from an agar culture infested with nemas; *e*, *f*, larger conidia from a pure culture. B, Portions of mycelium bearing non-constricting loops. C, A nema snared in two loops: *a*, one of the loops still attached to parent filament, several pouch-like structures thrust into the interior of the animal, the latter still actively struggling; *b*, 5 hours later, both loops detached, mycelial hyphae extending the entire length of the animal, not showing only occasional feeble movement.

Fig. 17.—A, Conidiophore and attached conidium, the former shown in several sections, *a*, *b* and *c* representing corresponding points on these sections. *B*, Portion of mycelium with attached constricting loops, the loops being open in *a* and *b*, and partly closed in *c*. C, Nema captured in constricting loop.

Fig. 18.—A, Conidiophore and conidia from mite-infested culture, the conidiophore drawn in several sections, *a* and *b* representing corresponding points on these sections, *c–i* conidia showing transitions from elongated 1-septate type to inflated 2-septate type. B, Constricting loops from mite-infested culture, *a* in open condition, *b* and *c* in completely closed condition.

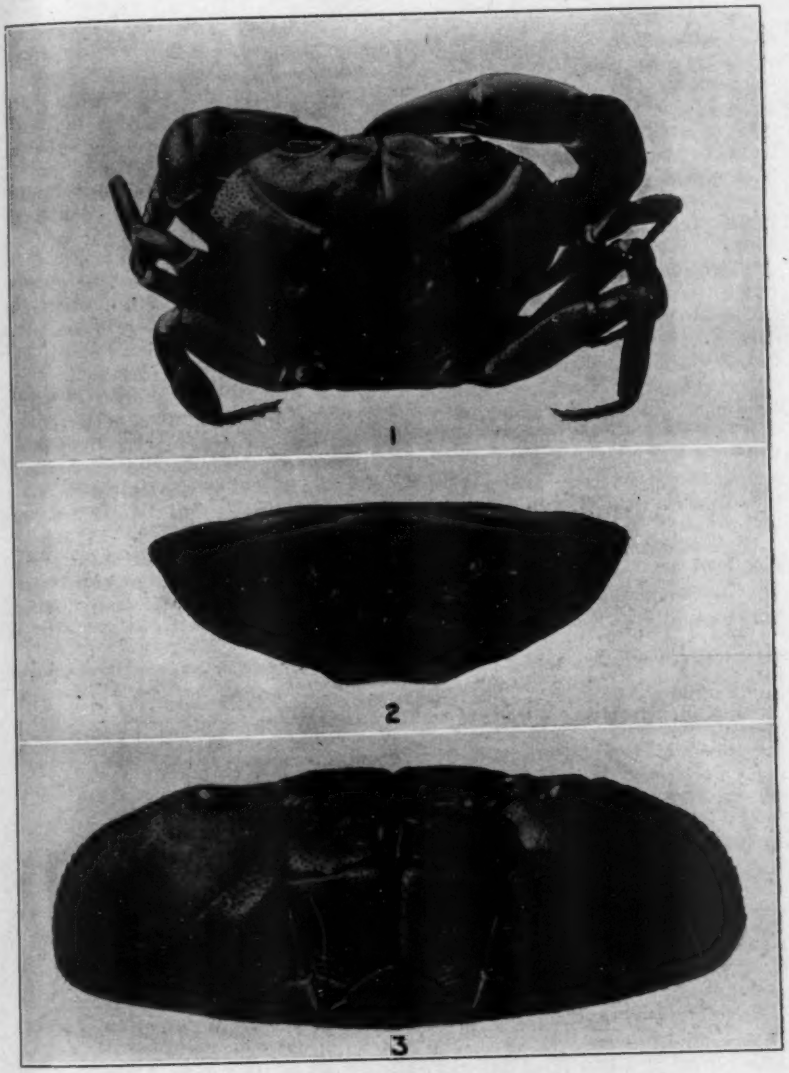
septate type are produced, and as the conidiophores (Fig. 18, A, *a*, *b*) are closely similar to those of the fungus shown in Figure 13, it is not certain that a species separate from the latter is represented here.

ZOOLOGY.—*The generic names* Cephalobellus *Cobb, 1920 and* Scarabanema *Christie, 1931 (Nematoda).*[1] JESSE R. CHRISTIE, Bureau of Plant Industry. (Communicated by G. STEINER.)

Cobb (1920) described *Cephalobellus papilliger* as a new genus and new species of nematode parasite from the larva of an unidentified lamellicorn beetle collected in New South Wales, Australia. He described only the male and no figure was published. Christie (1931) proposed the genus *Scarabanema* describing as type species *Scarabanema cylindricum*, a parasite now known from the larvae of several scarabaeid beetles. In the genus *Scarabanema*, Christie also placed *Thelastoma brevicaudatum* Leidy, 1851 and *Oxyuris leuckarti* Hammerschmidt, 1838. Only the females of these species are known and so far as one can judge from the meager descriptions available, both resemble *Scarabanema cylindricum* rather closely. They differ, however, in the size of the eggs. For the egg of *Thelastoma brevicaudatum*, Leidy gives 1/285 inch long by 1/1000 inch broad, or approximately 89 microns long by 25 microns wide, and for the egg of *Oxyuris leuckarti*, Hammerschmidt gives 1/25 to 1/20 Vienna line long by 1/30 Vienna line wide or approximately 84 to 100 microns long by 70 microns wide. In either case the difference seems too great to fall within the limits of variation for a single species and Christie (1931) deemed it advisable to retain both *Thelastoma brevicaudatum* and *Oxyuris leuckarti* as distinct species placing them in the genus *Scarabanema*.

A comparison of the male of *Cephalobellus papilliger* as described by Cobb (1920) and the male of *Scarabanema cylindricum* as described and figured by Christie (1931) shows no difference which would serve as a basis for retaining the latter as a valid species. Therefore the genus *Scarabanema* Christie, 1931 falls as a synonym of the genus *Cephalobellus* Cobb, 1920 and *Scarabanema cylindricum* Christie, 1931 becomes a synonym of *Cephalobellus papilliger* Cobb, 1920. The genus *Cephalobellus* also contains the following species: *Cephalobellus brevicaudatus* (Leidy, 1851) new combination and *Cephalobellus leuckarti* (Hammerschmidt, 1838) new combination.

[1] Received May 2, 1933.



Figures 1–3. *Pseudothelphusa guerreroensis*, n. sp.

Fig. 1.—Dorsal view, ×1½. Fig. 2.—Anterior view of front and orbits, ×2. Fig. 3.—Ventral view of forward half, ×nearly 3.

ZOOLOGY.—*A new species of* Pseudothelphusa *from Mexico.*[1] MARY J. RATHBUN, Smithsonian Institution.

Pseudothelphusa guerreroensis, n. sp.

Resembles *P. tuberculata*[2] in its rough surface, crowded but minute denticles on the lateral margin, well marked cervical suture, deep, anterior median suture, widening behind the oblique epigastric lobes; its shallow front, upper margin coarsely granulate and continued backward above the base of the eyestalk; the stout chelipeds, with palms swollen, upper and lower margins convex, and a large tubercle on outer surface at base of fingers. Differs from *tuberculata* in its narrower carapace, proportion of length to width 1:1.51, in *tuberculata* 1:1.6; greater fronto-orbital width in proportion to carapace width, 0.6 as against 0.57 in *tuberculata;* orbits in front view more quadrate, the upper and lower margins nearly parallel, while in *tuberculata,* the orbits are more oval; tooth absent from anterior end of lateral margin of carapace; a small round depression present behind outer angles of front and in horizontal line with extremities of anterior mesogastric outline; ischium of outer maxilliped broad, increasing in width distally but shorter than in *tuberculata,* merus very short and wide; its greatest length only $\frac{2}{3}$ of its width.

P. masimbari,[3] also closely related to the new species, has stronger denticles on the lateral margin, much less prominent epigastric lobes, a front deeper at the extremities and reaching downward to a level with the middle, maxillipeds of the type of *tuberculata,* and moreover lacks a tubercle at distal end of palm.

Type-locality:—Mexico: Malinaltepec, south of Teopa, Guerrero; Prof. L. Schultze, S.J., collector; April 30, 1930; Zool. Mus., Berlin; received through Dr. A. Schellenberg; 1 female holotype (23153, Bn.M.); 1 small female paratype (66850, U.S.N.M.).

[1] Received April 20, 1933. Published with the permission of the Smithsonian Institution.

[2] RATHBUN. Bull. Mus. d'hist. nat. 2: 60. 1897. Guatemala.

[3] Smithsonian Misc. Coll. 59: 13. 1912 Canal Zone.

SCIENTIFIC NOTES AND NEWS

Prepared by Science Service

NOTES

Chance to Restore Water Areas.—Unemployment-relief programs may offer a splendid chance to establish water areas for our migratory waterfowl, PAUL G. REDINGTON, Chief of the Bureau of Biological Survey, told the Izaak Walton League of America at its annual convention held recently in Chicago. "Deforestation and erosion, with the resultant depletion of water areas," said Mr. Redington, "have worked no good to man, beast, or fowl. There must be a real renaissance if we are to program a wide intensive effort to build up our diminishing water resources, and I believe that the time now appears ripe to tackle the situation which confronts us in many States." The convention called upon Federal and State officials and the public to begin a far-reaching program to this end and adopted a resolution urging that water restoration be included in the Federal reforestation program.

Wild-Life Exhibit at Chicago Exposition.—To emphasize the need for a permanent program of conservation, the Biological Survey has cooperated with the Department of Agriculture Office of Exhibits in preparing a wild-life exhibit for the Century of Progress exposition in Chicago. Specimens of mammals and birds have been mounted in a scene representing a valley in the middle of which is a winding stream bordered by a meadow, with rolling foothills and forested uplands on either side. The foreground represents a lake and brook amid trees, with undercover of shrubs and woodland grasses on one side and drier upland country on the other. The Department's entire 18-unit exhibit has been installed in the United States Government building at the exposition.

National Park Service.—Secretary of the Interior HAROLD L. ICKES has placed on record his unalterable opposition, and that of his department, to any plan for damming Lake Yellowstone or in any other way diverting Yellowstone's streams and lakes to commercial use.

Several National Park Service officials attended the meeting of the National Conference on State Parks held at Bear Mountain in the Palisades Interstate Park, May 25, 26, and 27.

Director ALBRIGHT was presented with the 1933 Pugsley Gold Medal for his services as superintendent of Yellowstone National Park and as Director of National Parks. The awarding of gold, silver and bronze medals annually in recognition of outstanding public service in the establishment and development of national, state, county and municipal parks in the United States, was established in 1928 by Mr. CHESTER D. PUGSLEY of Peekskill, N. Y., in honor of his father, Hon. CORNELIUS AMORY PUGSLEY.

Director Albright reported on the emergency conservation work being carried on in the national parks, and Assistant Director H. C. BRYANT addressed the conference on the subject of trends in the educational program of the national parks.

Geologist EARL A. TRAGER and Senior Park Naturalist and Forester ANSEL F. HALL installed National Park Service exhibits at the Century of Progress exposition at Chicago.

Dr. CARL P. RUSSELL, Field Naturalist of the National Park Service, addressed the Chicago meeting of the American Association of Museums on June 14.

The Committee on Libraries in the National Parks of the American Library Association, headed by Mr. C. EDWARD GRAVES, has prepared a plan of development for national park libraries. This plan was presented to the Secretary of the Interior on April 12, and it is hoped that financial means for putting the plan into operation will be forthcoming in the near future.

Department of Terrestrial Magnetism.—J. W. GREEN attended the meetings of the Fifth Pacific Science Congress at Vancouver and Victoria, Canada, June 1 to 14, as a representative of the Carnegie Institution of Washington and the Department of Terrestrial Magnetism. At these meetings he presented six papers by members of the Department, all pertaining to terrestrial magnetism and electricity with special reference to the Pacific region. H. W. GRAHAM, also of the Department of Terrestrial Magnetism, who has been at the Hopkins Marine Station, Pacific Grove, California, studying biological material collected by the "Carnegie," also attended the meetings, where he presented five additional papers.

Dr. M. A. TUVE and O. H. GISH attended the meetings of the American Physical Society, American Meteorological Society, and the American As-

sociation for the Advancement of Science at Chicago, on June 19–24. On June 23, Dr. TUVE presented at the Nuclear Physics Symposium of Section B, of the American Association for the Advancement of Science and the American Physical Society, a paper on *Disintegration experiments on elements of medium atomic number.*

During the summer sessions at the Johns Hopkins University, a special series of lectures has been arranged by the Department of Chemistry on *Recent developments in chemistry.* In a group of these lectures on *Chemistry and physics in cancer* Dr. TUVE is to give a talk on the subject of *Supervoltage radiations.*

New Insecticidal Fumigant.—In view of the high toxic hazard of hydrocyanic acid gas to personnel in connection with fumigation, the Bureau of Medicine and Surgery, Navy Department, has recently conducted a study of carboxide gas as an insecticidal fumigant for bedbugs and cockroaches for application aboard naval vessels. Carboxide gas is a mixture by weight of 9 parts of carbon dioxide and 1 part of ethylene oxide, the carbon dioxide removing the fire hazard and practically doubling the toxicity of the associated ethylene oxide. Carboxide gas was found to be effective in comparatively small dosages such as to render it economically practicable for conveniently short periods of exposure. With ordinary care a gas mask is not required for fumigation with carboxide and expert personnel is unnecessary.

A detailed report of this study will appear in the July, 1933, number of the United States Naval Medical Bulletin under the caption *Carboxide gas: A new insecticidal fumigant for bedbugs and cockroaches,* by Captain E. W. BROWN, Medical Corps, United States Navy.

George Washington University School of Medicine.—The following new full-time appointments have been announced in the School of Medicine, George Washington University: EDWARD BRIGHT VEDDER, M.D., as Professor of Experimental Medicine and Executive Officer, Department of Pathology and Experimental Medicine; WILLIAM HENRY WALLER, Ph.D., as Instructor in Anatomy; JESSE HARMON, B.S., Ph.D., as Instructor in Biochemistry; HUBERT SCOTT LORING, B.S., Ph.D., as Instructor in Biochemistry; JAMES LESLIE SNYDER, B.S., M.D., as Instructor in Pathology; JOHN RALSTON PATE, A.B., M.D., as Teaching Fellow in Anatomy.

NEWS BRIEFS

Two new national-forest primitive areas have been set aside by the Forest Service. They are in the Shoshone National Forest in Wyoming, and will be known respectively as the North and the South Absaroka Primitive Areas.

Employees of the Federal Government who develop patentable inventions need not assign the patents thereon to the United States Government nor grant the Government exclusive rights to the use of the inventions, in cases where they were not specifically assigned to work out the inventions concerned, the Supreme Court recently ruled in the suit of the Government against the Dubilier Condenser Corporation. The opinion was concerned with three radio inventions brought forth by F. W. DUNMORE and P. D. LOWELL while they were employed at the Bureau of Standards, Department of Commerce.

Two new fungus allergens, *Alternaria*, found in atmospheric dust, and *Trychophyton*, a skin parasite, have been recognized by Dr. HARRY S. BERNTON, a Washington physician, and Dr. CHARLES THOM, of the U. S. Department of Agriculture.

Hurricane warnings issued by the U. S. Weather Bureau this year will have the advantage of news direct from the sea areas. Under a new plan worked out by E. B. CALVERT, chief of the forecast division, ships at sea in regions known or suspected to be generating hurricanes will receive radio requests for data, which will be incorporated into the announcements sent out by the Weather Bureau.

Men trained in forestry, entomology, plant pathology, biology, and other sciences applicable in forest work, not now employed, may be able to find positions in the supervisory personnel of the emergency reforestation "army," the Forest Service has announced.

"Heavy" water, containing high proportions of hydrogen isotope 2 and oxygen isotopes 17 and 18 has been prepared at the Bureau of Standards by distillation, depending on its higher boiling point. It has also been segregated from "common" water by adsorption on activated charcoal.

Surgeon General ROBERT U. PATTERSON informed the Conference of State and Provincial Health Authorities at their meeting in Washington that the health of the men in the conservation camps is above average, and that no cause for anxiety over possible epidemics need be entertained.

The grain-raising regions of the West will experience a plague of grasshoppers this year, a survey by the Bureau of Entomology, U. S. Department of Agriculture, indicates. The eggs left in the soil by last year's insects have survived the winter in almost perfect condition, and recent hot weather is bringing about a practically 100 per cent hatch. Some of the states where the grasshoppers will be most numerous have little or no money to spend on poison baits for holding them in check.

New Minimum Temperature Record.—The U. S. Weather Bureau has accepted as official a minimum temperature of −66° F., observed February 9, 1933, at the Riverside ranger station in Yellowstone National Park; one of several stations in the park at which meteorological observations are made under the supervision of the Weather Bureau. This is the lowest temperature hitherto officially recorded in the United States; the previous extreme having been −65° F. at Fort Keogh, near Miles City, Montana, registered January 13, 1888.

From the report of this observation it appears that the temperature may actually have fallen below the value given above, as the index of the official thermometer was found as low as it would go, while an unofficial instrument in the immediate vicinity, constructed to register lower readings, showed a minimum temperature of −69° F. on the same day. A subsequent comparison of the official and unofficial thermometers, at higher temperatures, showed them in substantial agreement.

Submarine Deep and Peak.—The Navy Hydrographic Office received from the U.S.S."Ramapo" a radio report of a sonic sounding taken April 30, 1933, of 5501 fathoms in the southern end of the Tuscarora Deep about 250 miles southwest of Yokahama. The application in the Hydrographic Office of correction factors for sonic soundings from data obtained in this vicinity by the

ship "Carnegie" of the Carnegie Institution resulted in a corrected depth of 5,770 fathoms. This sounding is 611 fathoms greater than the greatest depth obtained in the Tuscarora Deep by the Japanese surveying ship "Manchu" in 1924, and ranks the new found deep as second only to the depth of 5,900 fathoms found by the German Cruiser "Emden" in the Mindanao Deep in 1927.

A submarine peak, jutting upward from water more than a thousand fathoms deep, was discovered on the night of May 4 by the U.S.S. "Patoka," Commander RALPH B. HORNER. Fathometer soundings indicated only 11 to 15 fathoms. The position of the "Patoka" at the time of shallowest soundings was latitude 49:25 north, longitude 129:20 west. This position is about 200 miles west north west of Cape Flattery, and 65 miles off Cape Cook, Vancouver Island.

PERSONAL ITEMS

Dr. LYMAN J. BRIGGS was confirmed as director of the National Bureau of Standards by the Senate during the last days of the special session.

Dr. DAVID FAIRCHILD, veteran plant explorer of the U. S. Department of Agriculture, has been designated as the recipient of the Public Welfare Medal of the National Academy of Sciences. The presentation will be made at the next annual meeting of the Academy.

Dr. F. B. LAFORGE and Dr. H. L. J. HALLER of the U. S. Department of Agriculture have been awarded the Hillebrand Prize of the Chemical Society of Washington, in recognition of their researches on the chemical structure of rotenone.

WATSON DAVIS has been elected Director of Science Service, succeeding the late Dr. EDWIN E. SLOSSON. Since Dr. Slosson's death in 1929 the directorship has been vacant.

Meeting in Paris recently, the Permanent Committee of the International Veterinary Congresses elected Dr. JOHN R. MOHLER, chief, Bureau of Animal Industry, U. S. Department of Agriculture, vice president, to succeed Dr. EMMANUEL LECLAINCHE, chief of the Government Veterinary Services in Paris. Dr. MOHLER will take an active part in the 12th International Veterinary Congress, to be held in New York City, August 15–19, 1934.

Dr. WILLIAM A. WHITE, superintendent of St. Elizabeth's Hospital, was re-elected president of the District Social Hygiene Society at a recent meeting of the Society's board of directors.

Mr. EDWARD J. PHELAN, Chief of the Diplomatic Division of the International Labor Office, spoke on *The International Labor Organization and the World Economic Conference*, at the Brookings Institution Residence, on Tuesday, May 16.

Medical Director EDWARD FRANCIS of the U. S. Public Health Service was awarded the degree Doctor of Science, *honoris causa*, by Ohio State University on June 23.

Surgeon CHARLES ARMSTRONG of the U. S. Public Health Service was awarded the degeee Doctor of Science, *honoris causa*, by Mt. Union College on June 6.

At the annual Medal Day exercises of the Franklin Institute in Philadelphia on May 17, Dr. D. J. MCADAM, JR., chief of the optical metallurgy section of the Bureau of Standards, received the Edward Longstreth medal.